OVERFLOW Analysis of the NASA Trap Wing Model from the First High Lift Prediction Workshop

Anthony J. Sclafani, Jeffrey P. Slotnick, John C. Vassberg
The Boeing Company, Boeing Research & Technology
Huntington Beach, California, USA

Thomas H. Pulliam, Henry C. Lee
NASA Ames Research Center
Moffett Field, California, USA

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Trap Wing OVERFLOW Analysis
Outline

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- Overset Grids
- Solver, Solution, and Dataset Information
- Convergence
- Results
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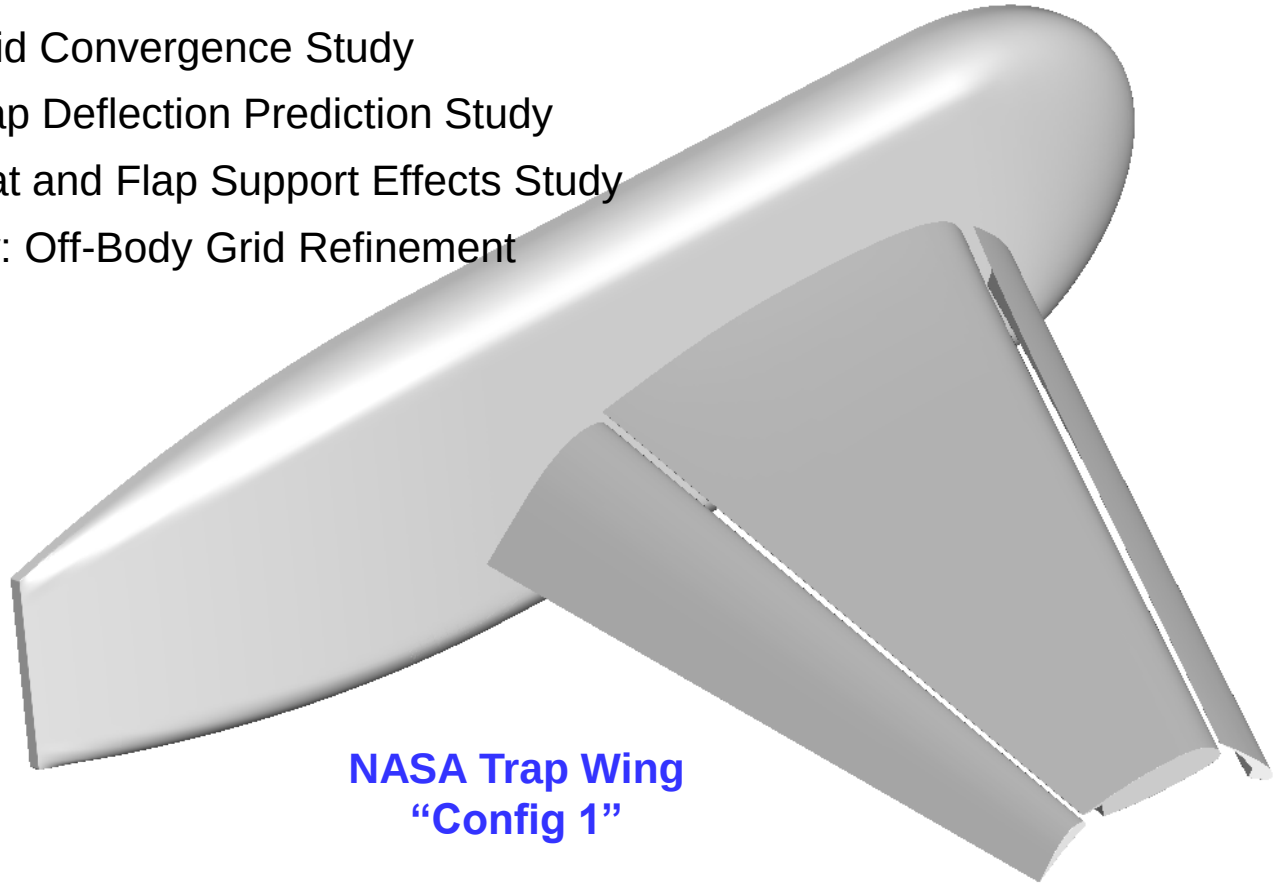
  - Test Case 2: Flap Deflection Prediction Study
  - Test Case 3: Slat and Flap Support Effects Study
  - Additional Study: Off-Body Grid Refinement
- Conclusions



NASA Trap Wing
"Config 1"

Geometry
Trap Wing Wind Tunnel Model Description

Reference quantities:

- $\Lambda_{c/4} = 30^o$
- $S_{ref} = 3172.032\ in^2$
- $c_{ref} = 39.634\ in$
- $b/2 = 85.054\ in$
- $AR = 4.56$

Analyzed two full-span flap configurations

- "Config 1" and "Config 8"
- Only difference is 5^o of flap deflection

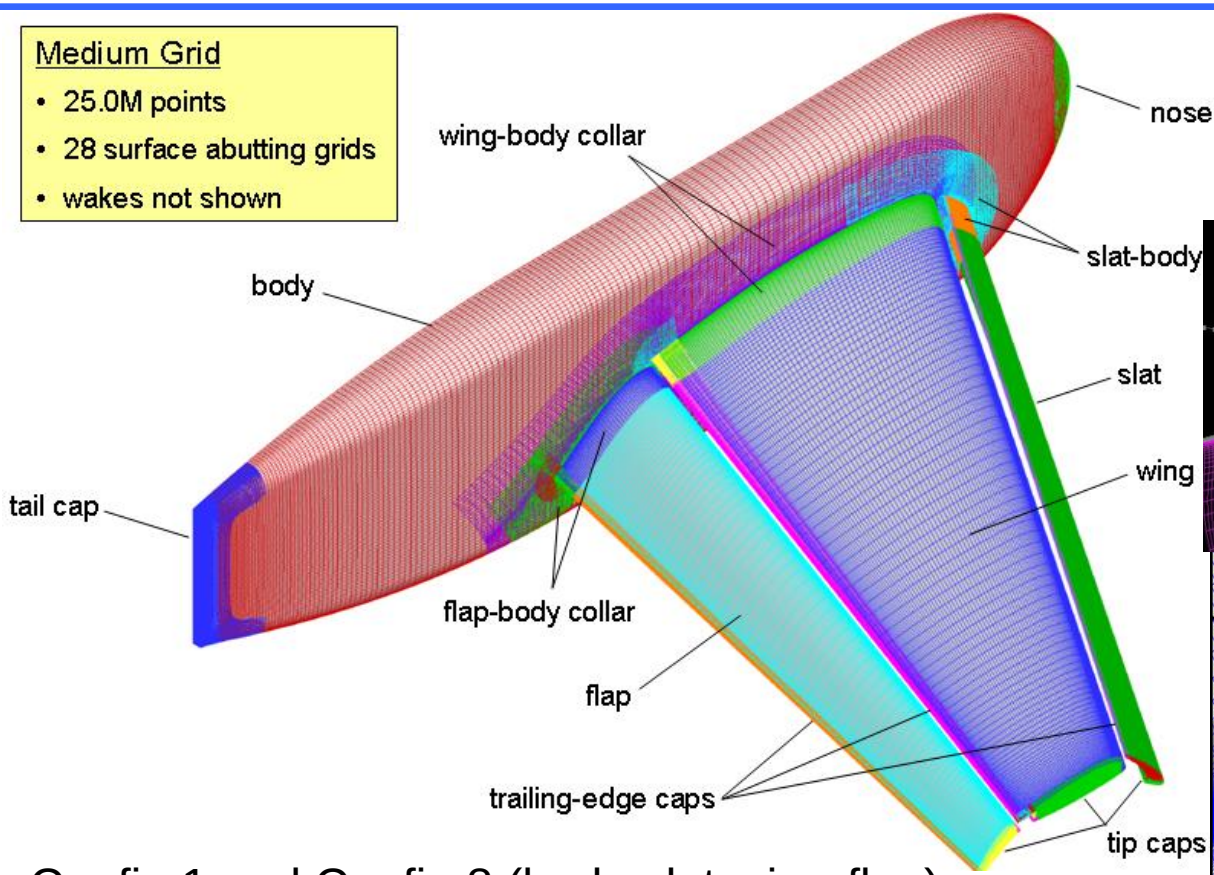
More information found in multiple references

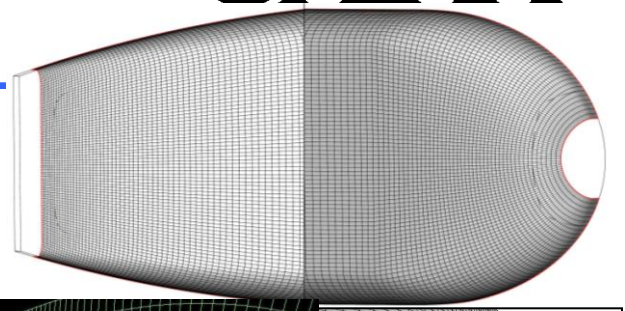
- AIAA Paper 2000-4217
- "Overview of the First AIAA CFD High Lift Prediction Workshop"

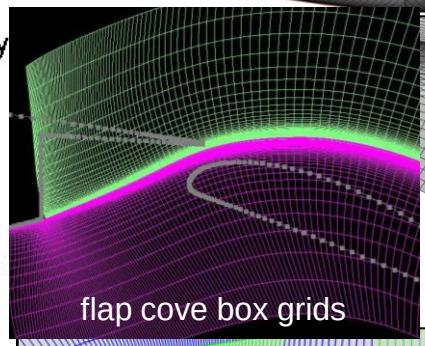
Overset Grids

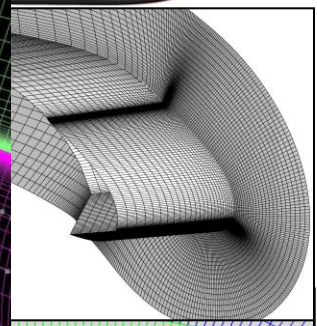
Grid Parameters and Images – Brackets Off

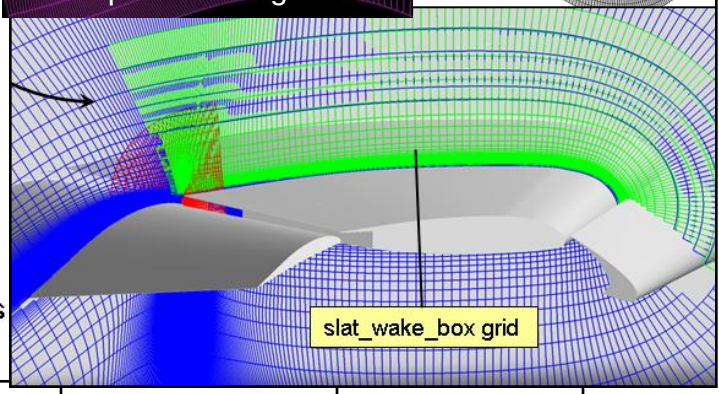
Medium Grid
- 25.0M points
- 28 surface abutting grids
- wakes not shown









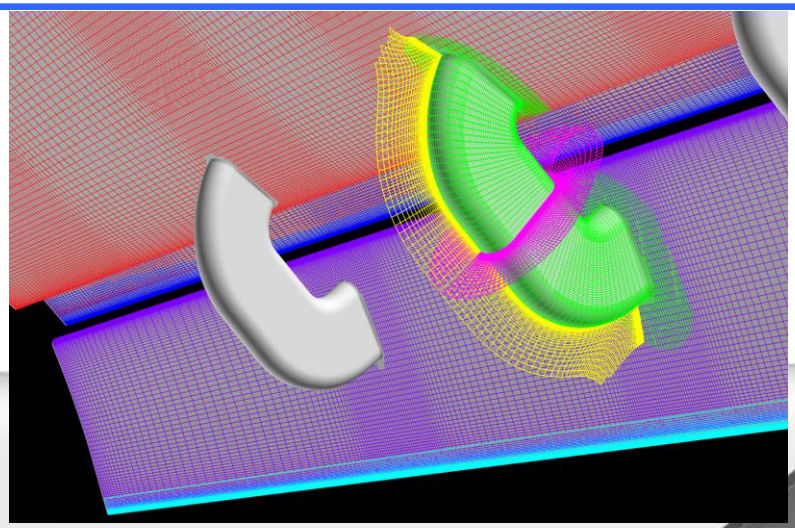


Config 1 and Config 8 (body-slat-wing-flap)

Grid	Points	$1/N^{2/3} \times 10^5$	1st Cell Size	y^+	Const. Cells	Stretching
Coarse	10,653,004	2.07	.00017 in	.87	2	1.25
Medium	24,965,818	1.17	.00013 in	.66	3	1.18
Fine	83,302,438	0.52	.00009 in	.44	4	1.12
Extra-Fine	281,560,012	0.23	.00006 in	.29	6	1.08

Overset Grids

Grid Parameters and Images – Brackets On



Medium Grid Sizes

- Brackets-off = 25.0 million
- Brackets-off with refined c-mesh grids = 47.0 million
- Brackets-on with refined c-mesh grids = 58.2 million

Solver, Solution, and Dataset Information
Boeing Study vs. NASA Study

Boeing Study

- OVERFLOW v2.1ad
- Majority of data generated using a default mode of operation
  - Roe upwind differencing
  - Spalart-Allmaras turbulence model version “fv3”
  - full Navier-Stokes
  - low-Mach preconditioning
  - exact turbulence model wall distance calculation
- Small subset of medium grid data generated using SA-RC
- Identical solution strategy employed for all cases analyzed
  - steady state
  - freestream initial conditions
  - maximum allowable Δt

NASA Study

- OVERFLOW v2.2
- Submitted data from multiple modes of operation
  - Roe, HLLC, central differencing schemes
  - Spalart-Allmaras turbulence model version “fv3” and Menter’s SST
  - full Navier-Stokes
  - low-Mach preconditioning
  - exact turbulence model wall distance calculation
- Small subset of medium grid data generated using SA-Ia
- Tailored solution strategy based on convergence behavior
  - steady state and time accurate
  - freestream initial conditions, restarts
  - minimize Δt

Solver, Solution, and Dataset Information
Boeing Study vs. NASA Study (continued)

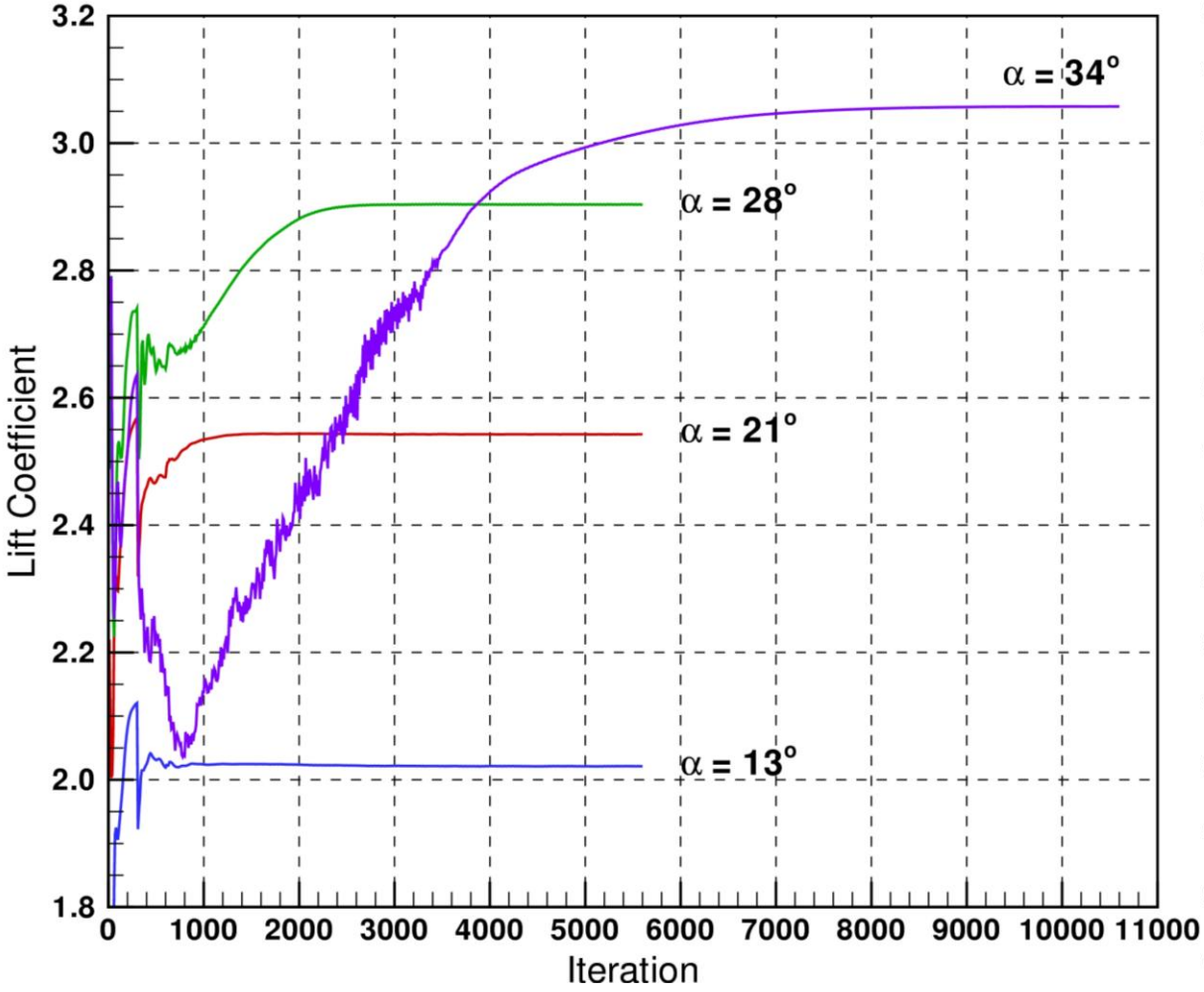
Dataset No.	Dataset Name	Workshop Entry No.	Source	Turbulence Model	Differencing Scheme	Test Case
1	B-SAfv3-Roe	003.01	Boeing, BR&T	SA-fv3	Roe upwind	1, 2, 3
2	B-SARC-Roe	n/a	Boeing, BR&T	SA-RC	Roe upwind	2
3	N-SAfv3-Roe	014.01	NASA ARC	SA-fv3	Roe upwind	1, 2, 3
4	N-SST-Roe	014.04	NASA ARC	SST	Roe upwind	1, 2, 3
5	N-SAfv3-HLLC	014.02	NASA ARC	SA-fv3	HLLC upwind	1, 2
6	N-SAfv3-central	014.03	NASA ARC	SA-fv3	Central	2
7	N-SAIa-Roe	014.05	NASA ARC	SA-Ia	Roe upwind	2

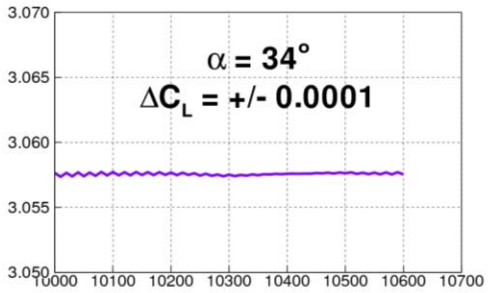
Test Case 1:	Grid Convergence Study	Required
Test Case 2:	Flap Deflection Prediction Study	Required
Test Case 3:	Slat and Flap Support Effects Study	Optional

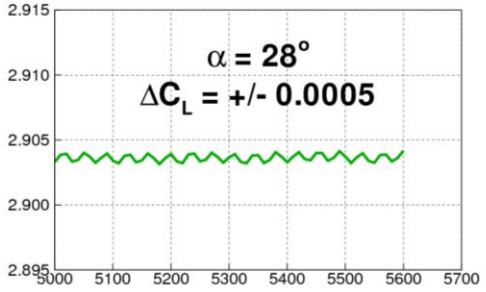
Convergence
Lift: Medium Grid

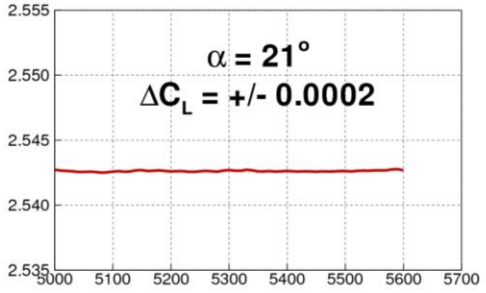
OVERFLOW Convergence Histories - Lift

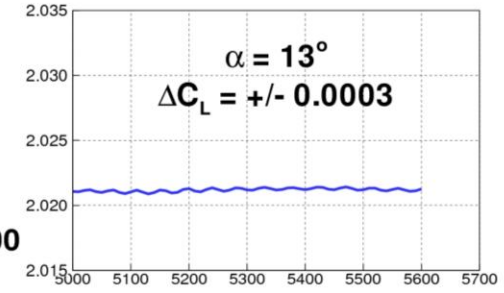
> Config 1 Medium Grid Solutions
> Slat/Flap Brackets Off
> Fully Turbulent, Free Air
> RN = 4.3 million, Mach = 0.2





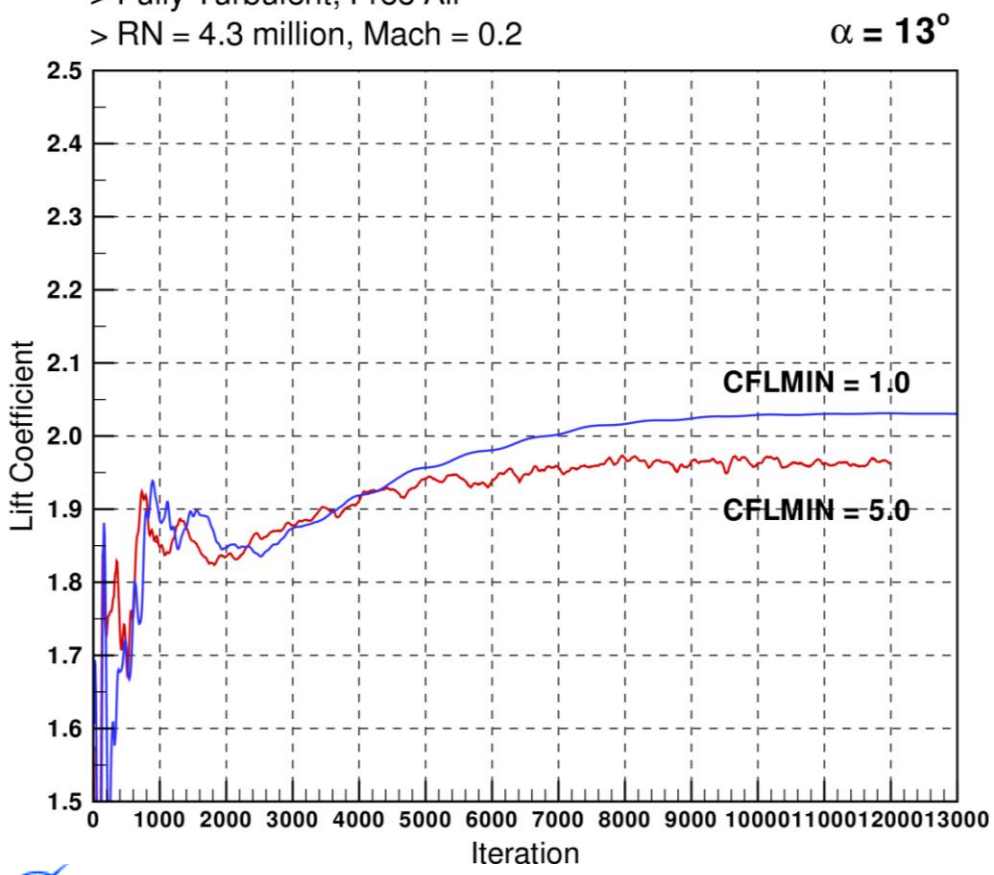


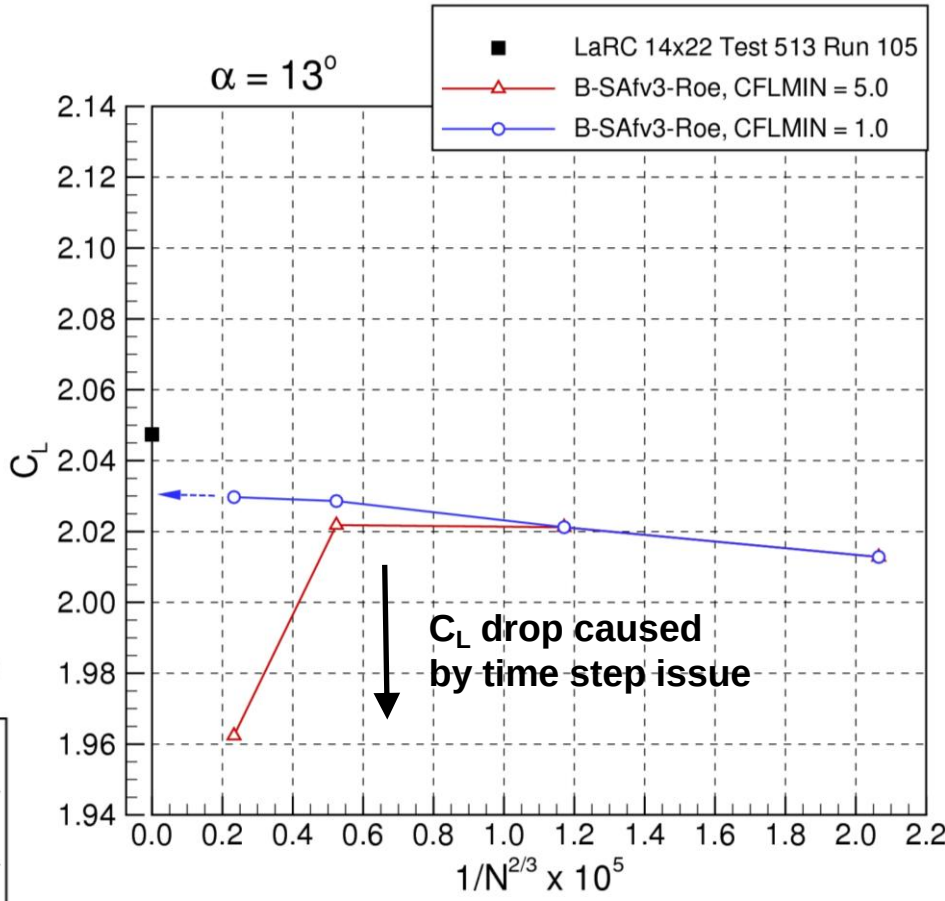


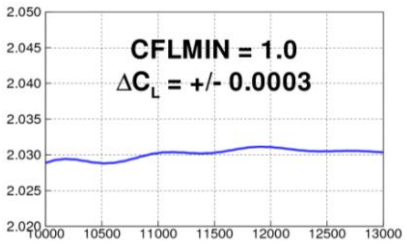


Convergence
Lift: Extra-Fine Grid

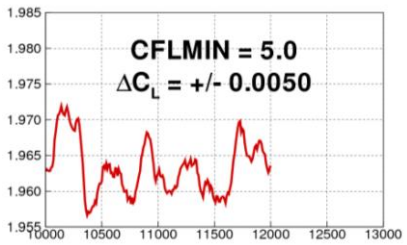
OVERFLOW Convergence Histories - Lift
> Config 1 Extra-Fine Grid Solutions
> Slat/Flap Brackets Off
> Fully Turbulent, Free Air
> RN = 4.3 million, Mach = 0.2







CONVERGED



NOT CONVERGED

Test Case 1

Grid Convergence Study

Test Case 1 – Grid Convergence Study

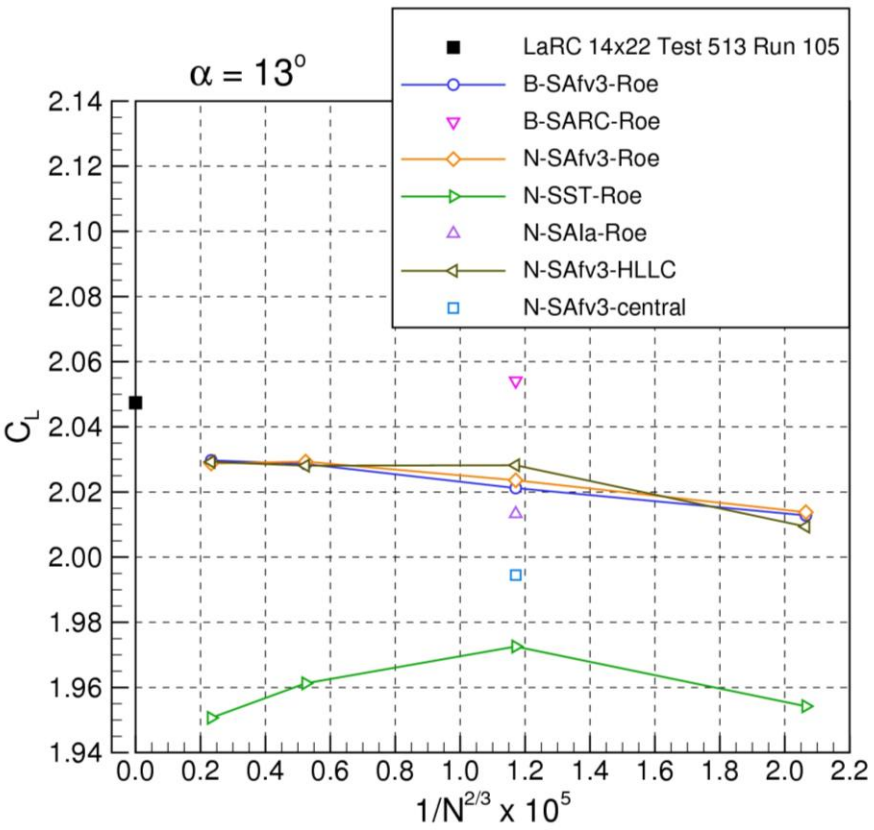
Config 1 Lift at $\alpha = 13^o$

Effect of Solution Strategy and Platform

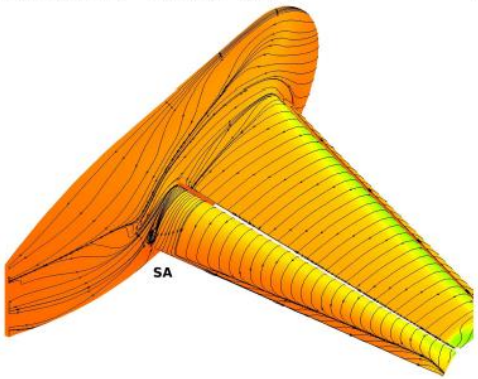
- Boeing and NASA results are nearly identical

Effect of Solution Algorithm

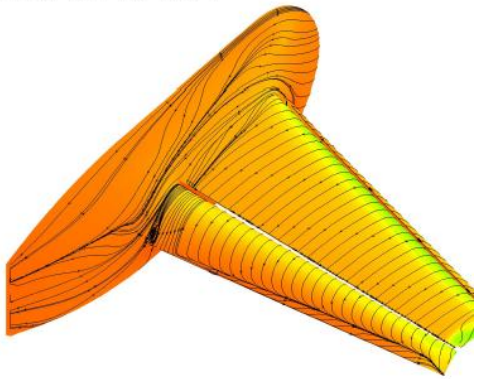
- HLLC results very similar to Roe, particularly for fine and extra-fine grids
- Central differencing gives less left for medium grid



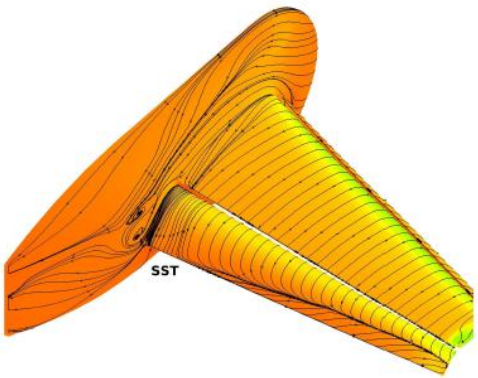
Medium Grid SA



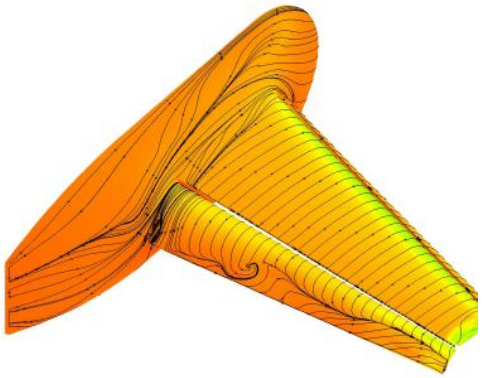
Fine Grid SA



Medium Grid SST



Fine Grid SST

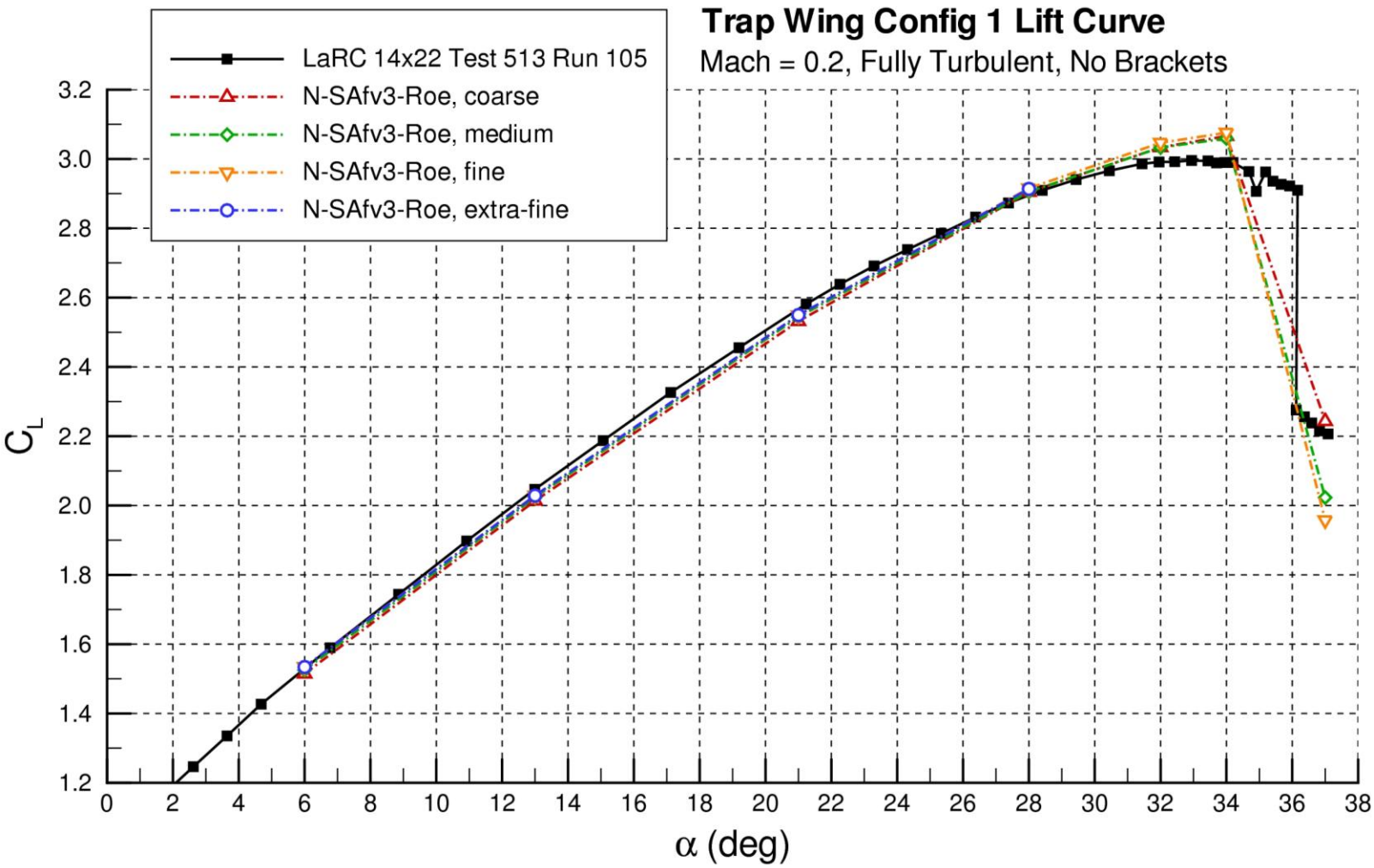


Effect of Turbulence Model

- Less lift from SA-Ia compared to SA-fv3
- More lift from SA-RC compared to SA-fv3
- Considerably less lift from SST compared to SA
- SST lift varies more with grid refinement

Test Case 1 – Grid Convergence Study
Config 1 Lift Curve

NASA Results with SA-fv3 and Roe upwind



- Grid refinement has little impact on lift curve through 28°
- Coarse, medium, and fine grid solutions predict the same α_{stall}

Test Case 1 – Grid Convergence Study

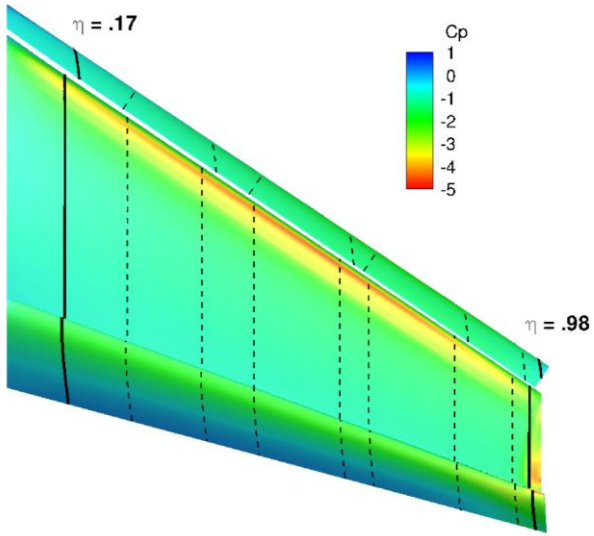
Config 1 Pressure Comparison at $\alpha = 13^o$

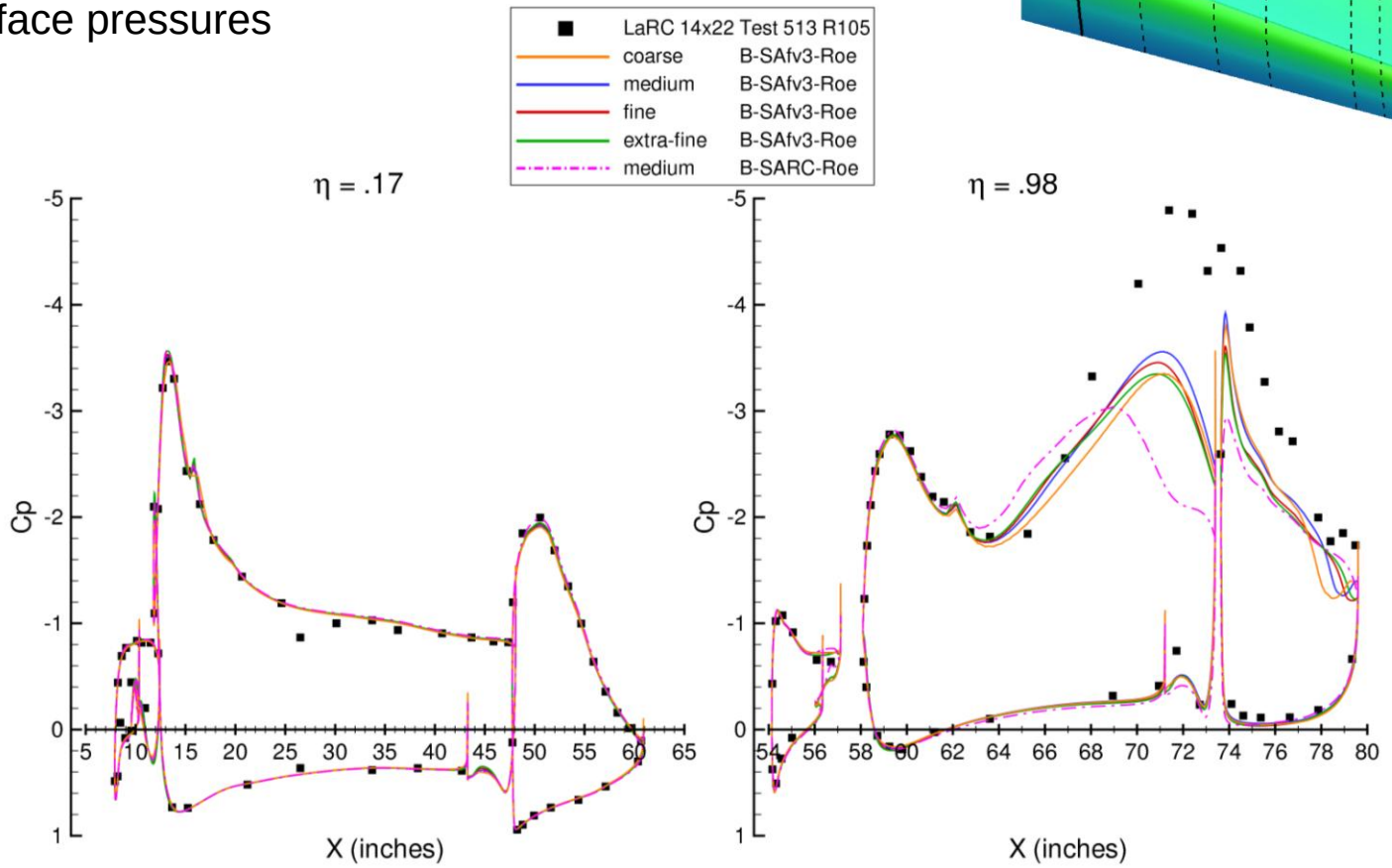
Inboard Comparison, $\eta = 0.17$

- very good agreement with test data
- no significant grid effect
- SA-RC matches flap suction peak

Tip Comparison, $\eta = 0.98$

- missed wing upper surface aft of ~.25c and flap upper surface pressures



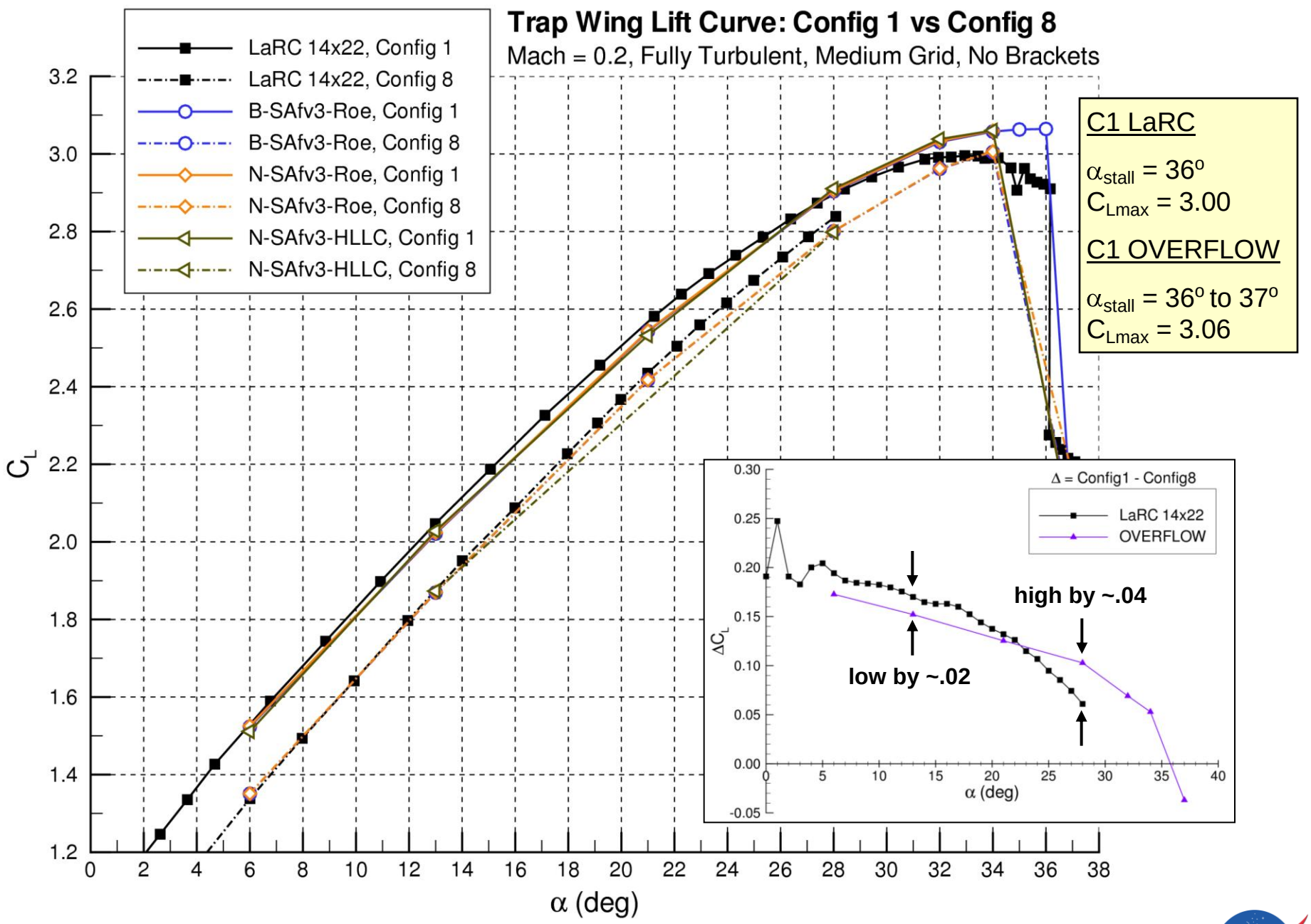


Test Case 2

Flap Deflection Prediction Study

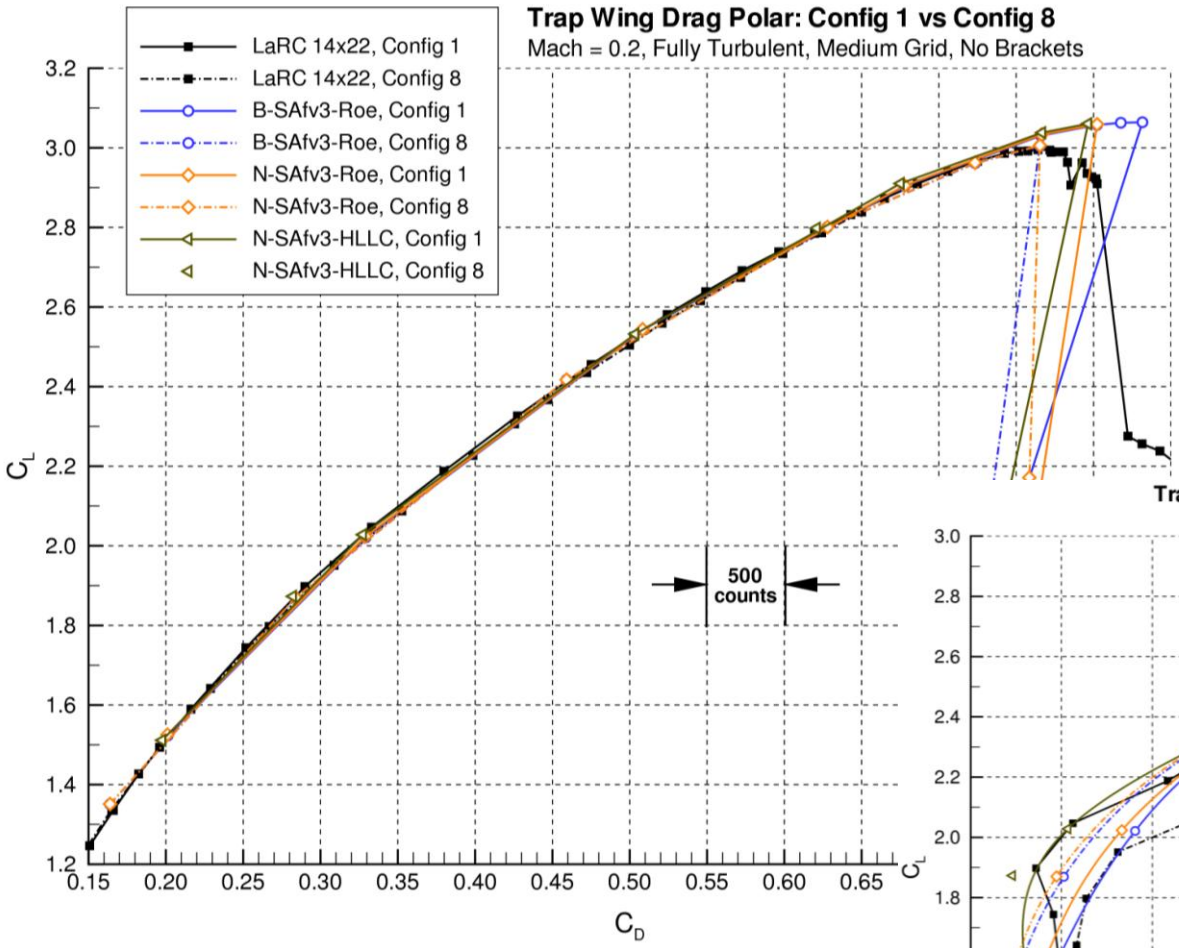
Test Case 2 – Flap Deflection Prediction Study

Lift Comparison: Config 1 vs. Config 8

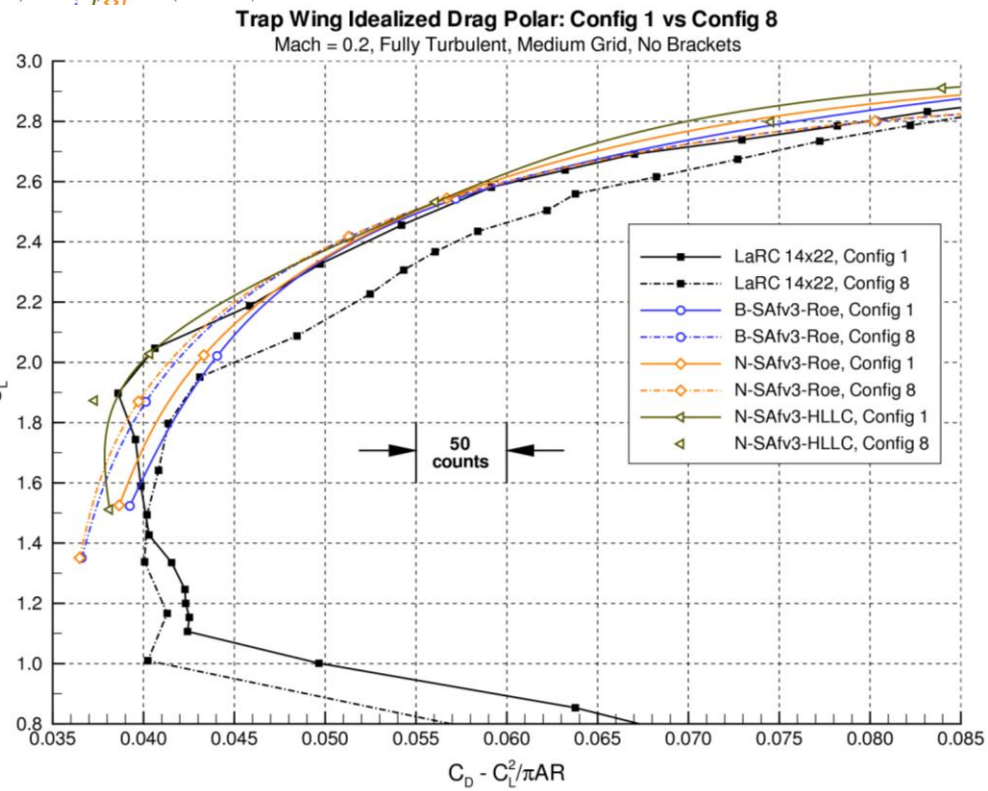


Test Case 2 – Flap Deflection Prediction Study

Drag Comparison: Config 1 vs. Config 8



"Idealized" Drag Polar

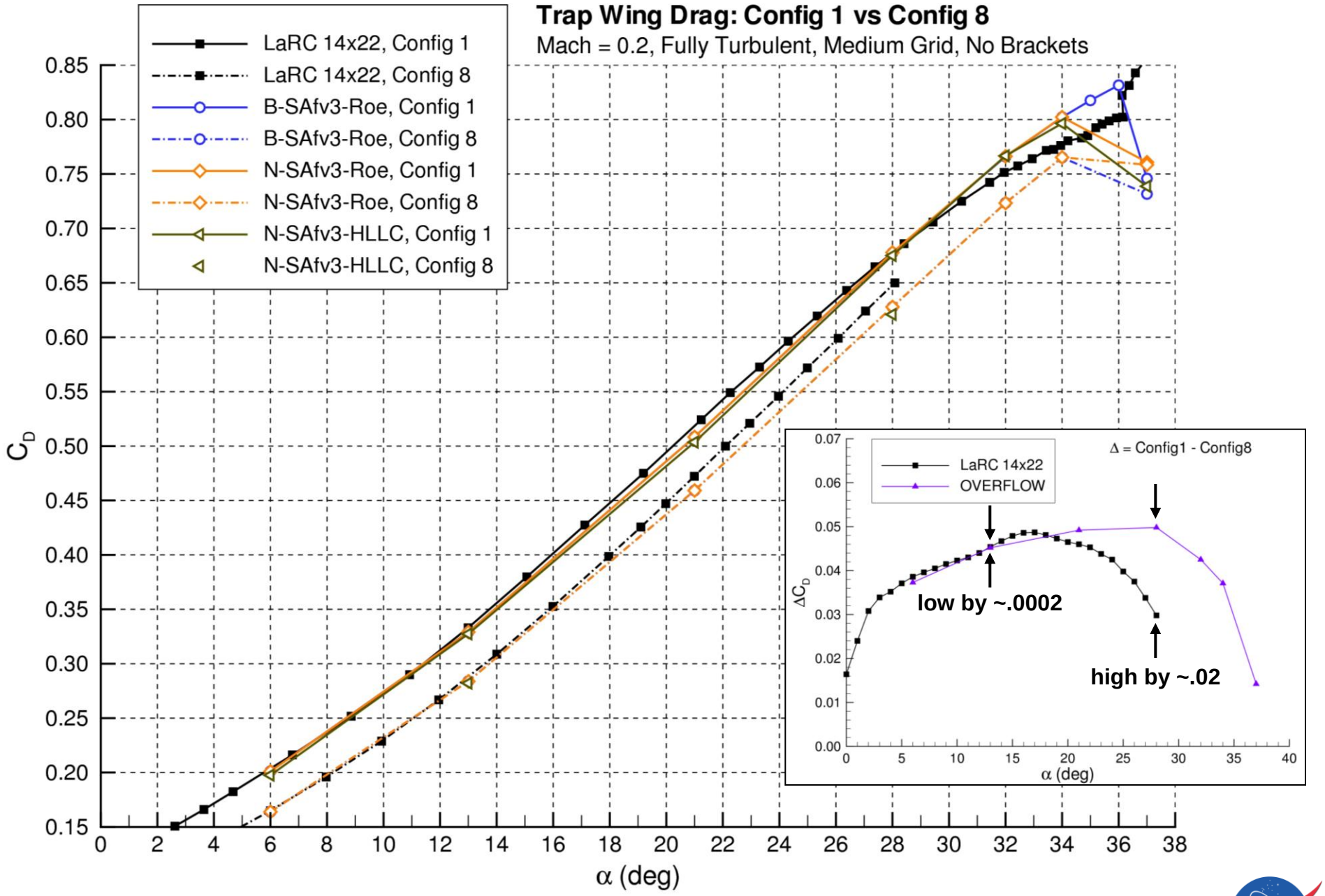


By removing idealized induced drag, a more detailed polar comparison can be made.

- LaRC data show cross-over C_L to be at 1.5, above which Config 8 has higher drag
- OVERFLOW C_L cross-over is at 2.4
- Larger difference seen in Config 8 polar

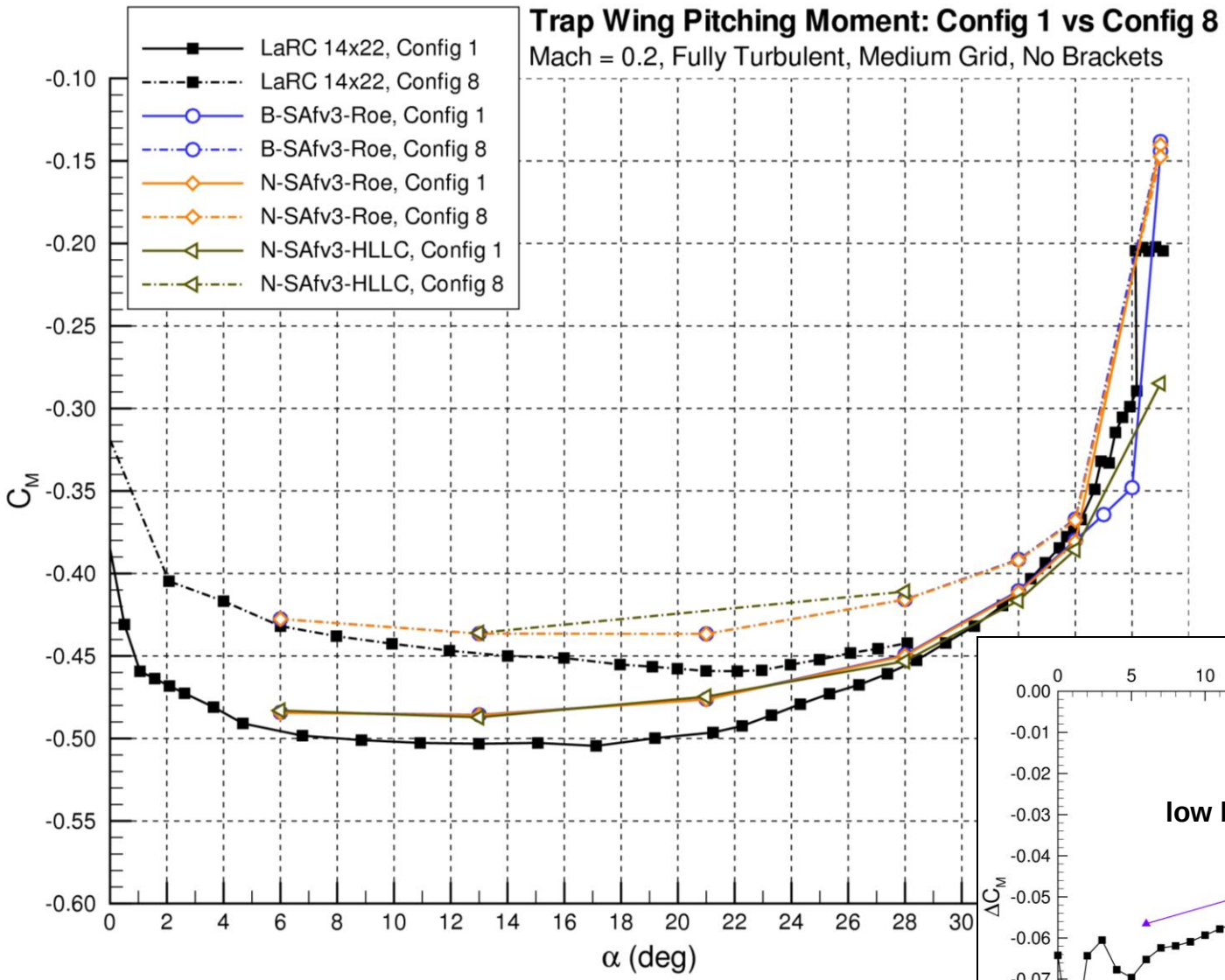
Test Case 2 – Flap Deflection Prediction Study

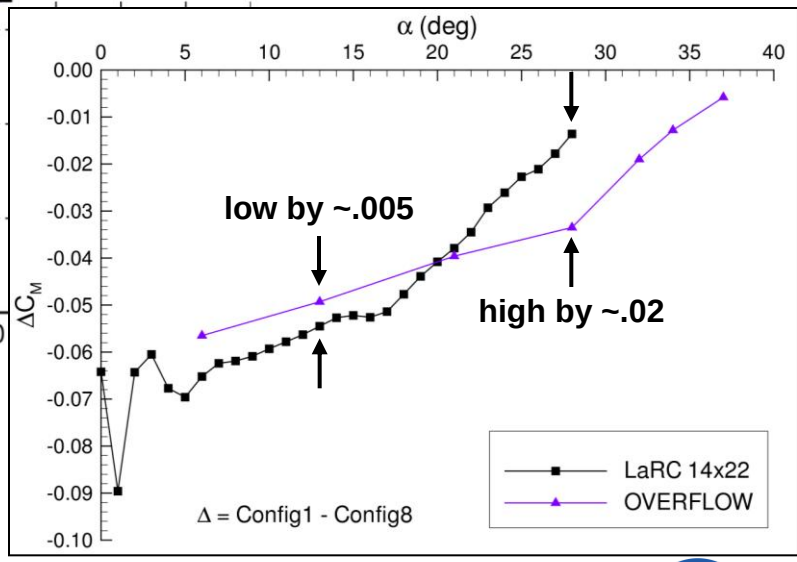
Drag Comparison: Config 1 vs. Config 8 (C_D vs α)



Test Case 2 – Flap Deflection Prediction Study

Pitching Moment Comparison: Config 1 vs. Config 8

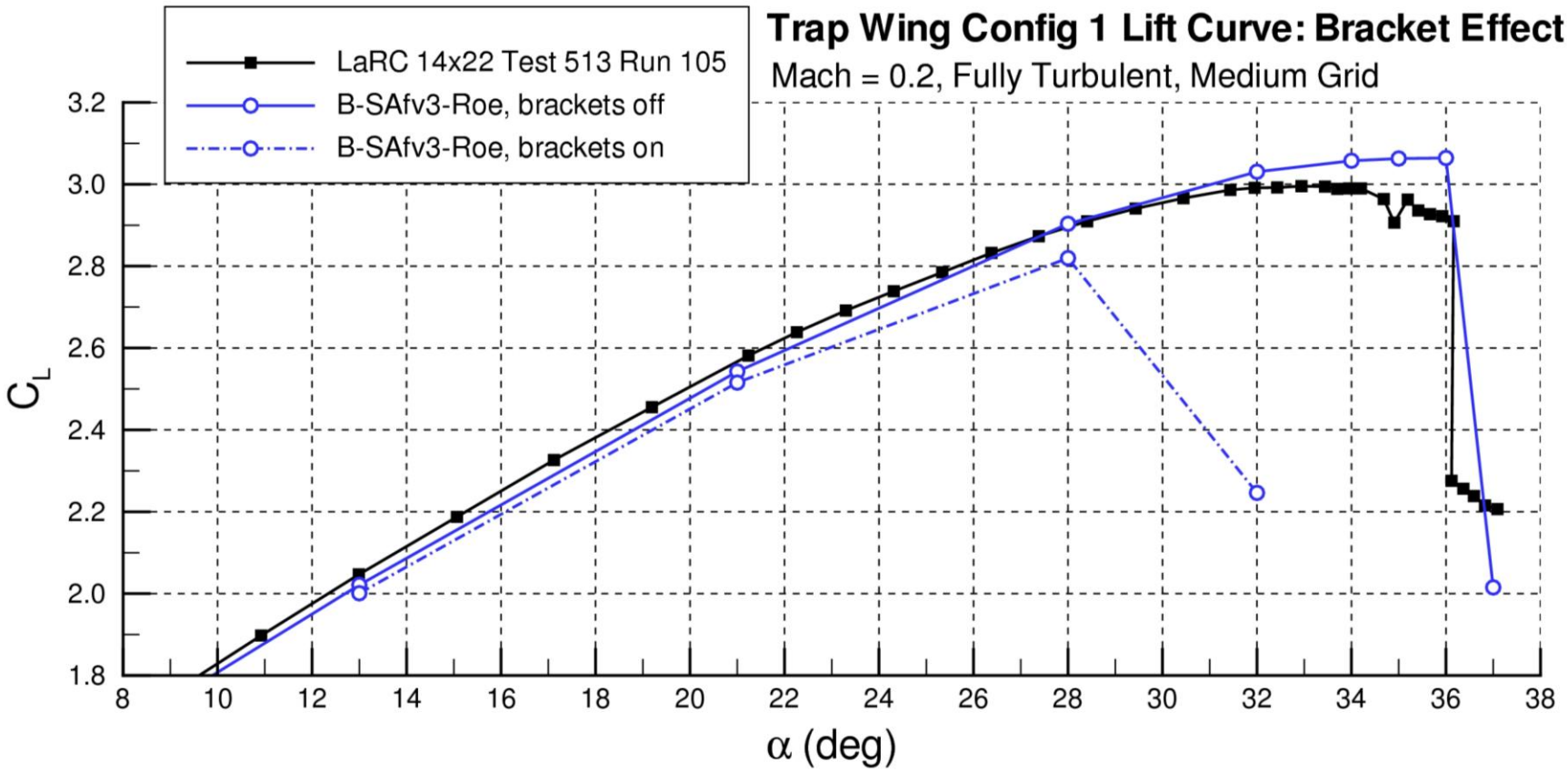




Test Case 3

Slat and Flap Support Effects Study

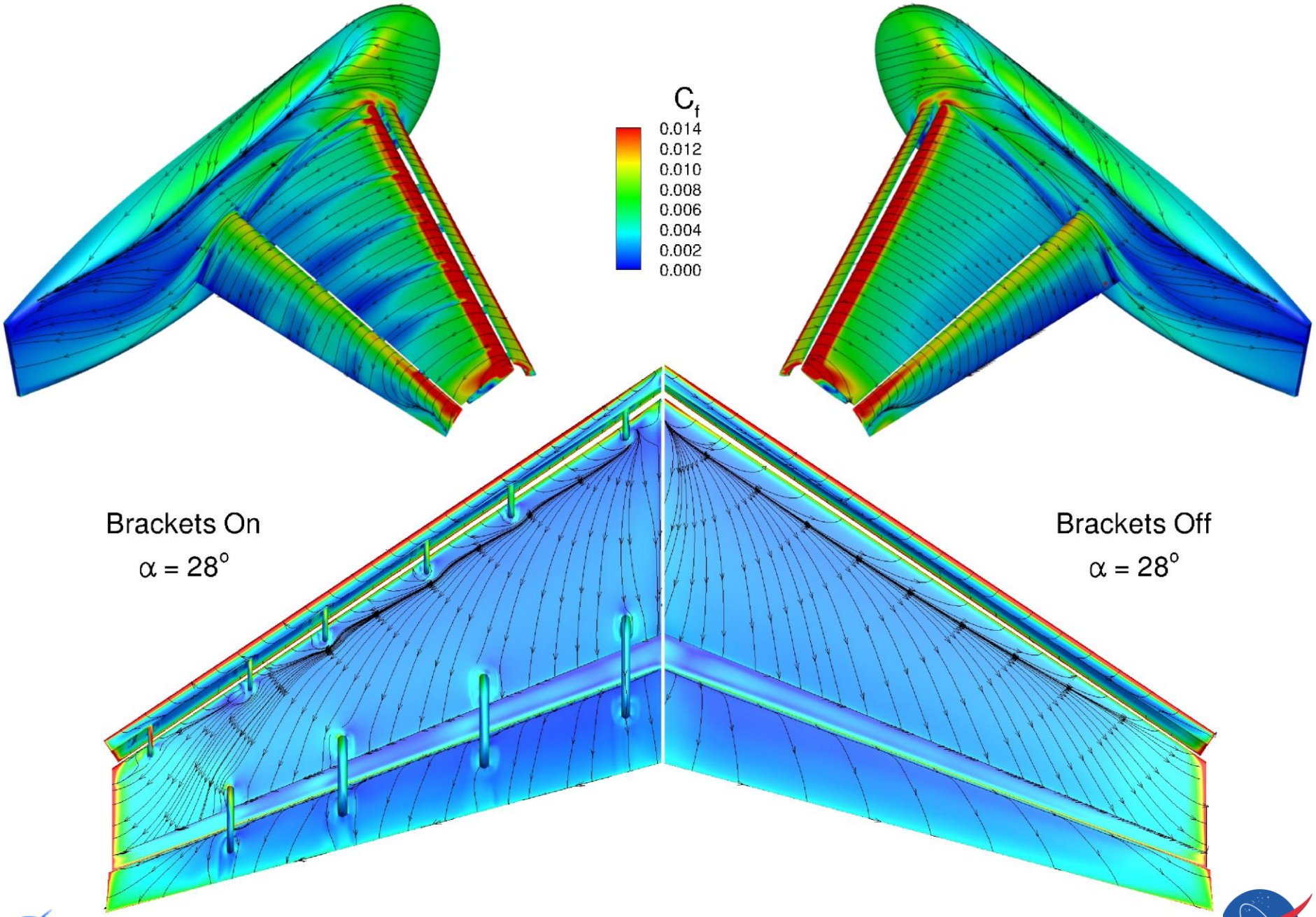
Boeing Results with SA-fv3 and Roe upwind



- Brackets reduce C_L by ~.02 at 13º and 21º
- C_L reduction grows to ~.08 at 28º
- By 32º, the bracket-on configuration is stalled
  - Early stall behavior may be eliminated with alternate solution strategies such as restarting from a lower alpha solution

Test Case 3 – Support Effects Study

Skin Friction and Surface Streamline Comparison

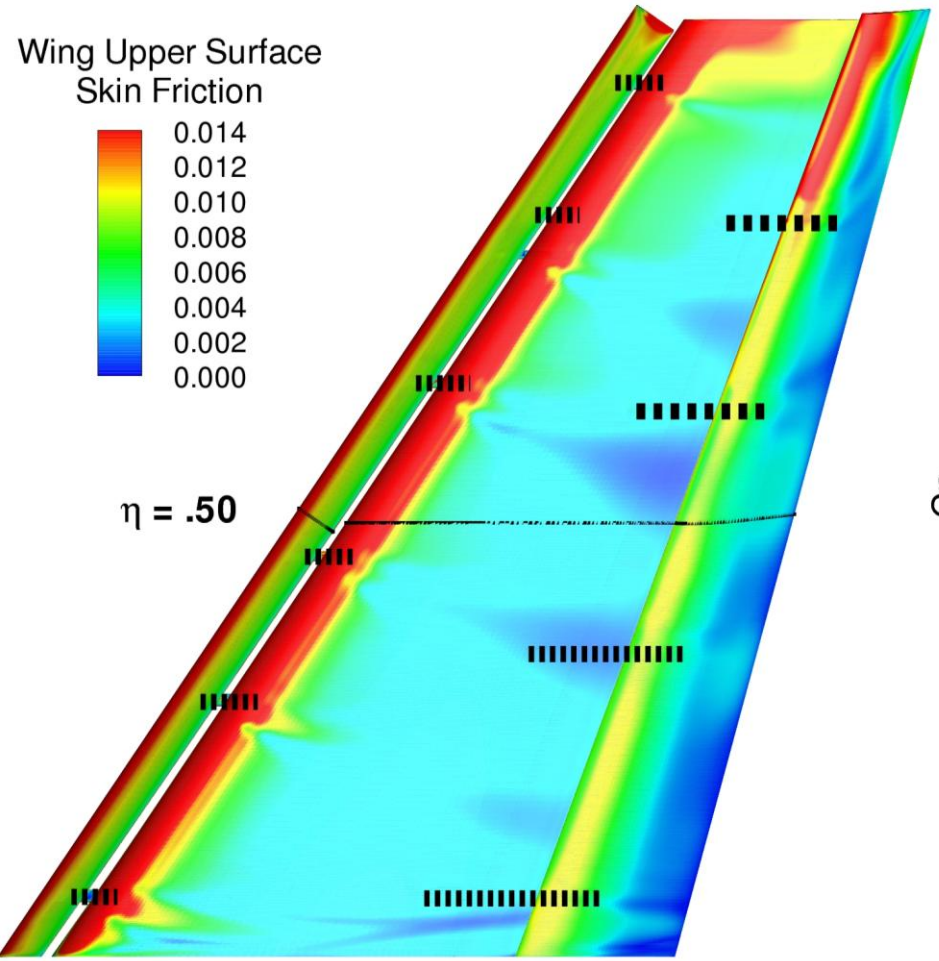


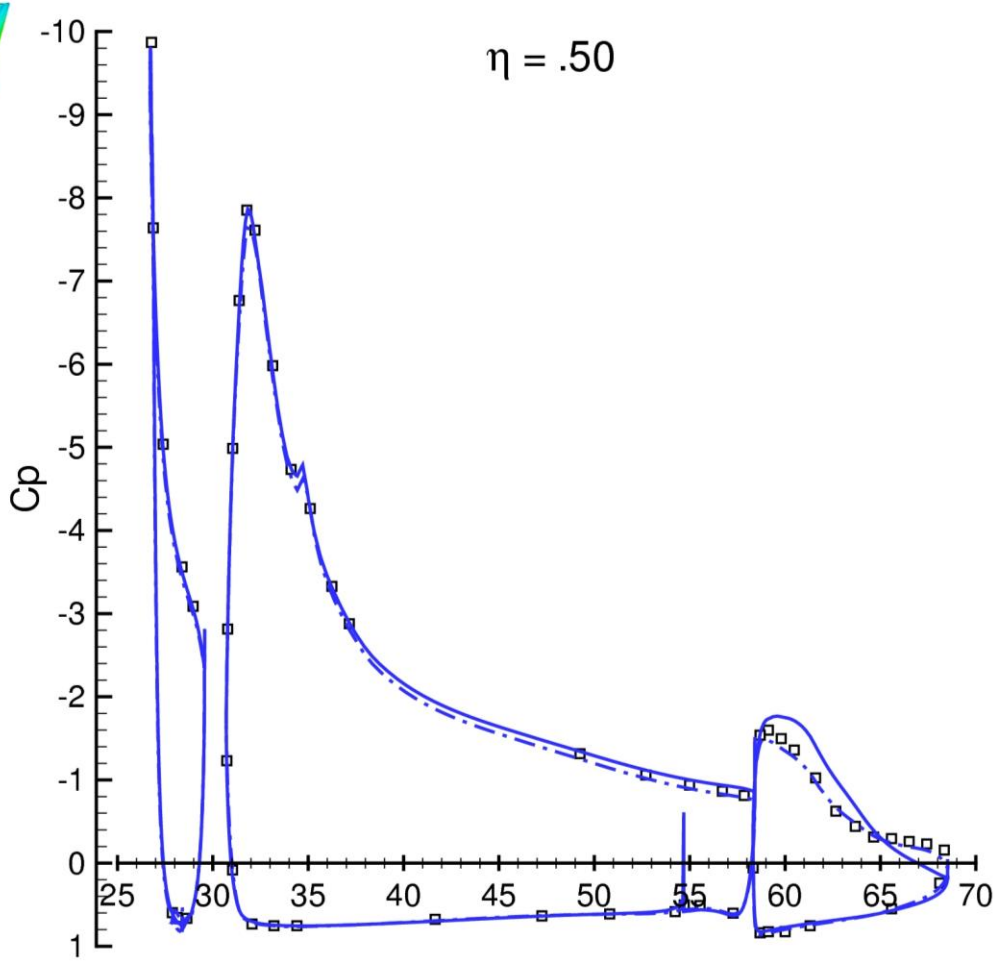
Test Case 3 – Support Effects Study
Pressure Comparison at α = 28°, η = 50%

Trap Wing Config1 Pressure Comparison

LaRC 14x22 vs OVERFLOW

RN_{MAC} = 4.3 million, Mach = 0.2, α = 28°



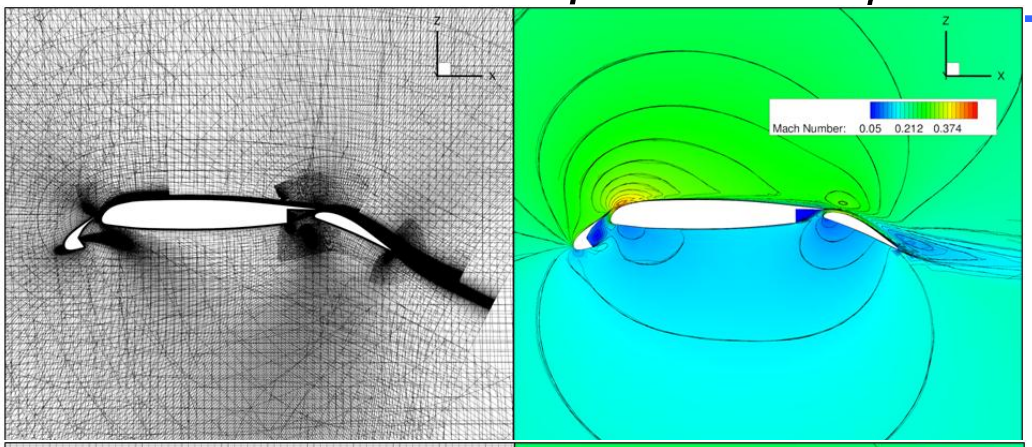


Additional Study

Off-Body Grid Refinement

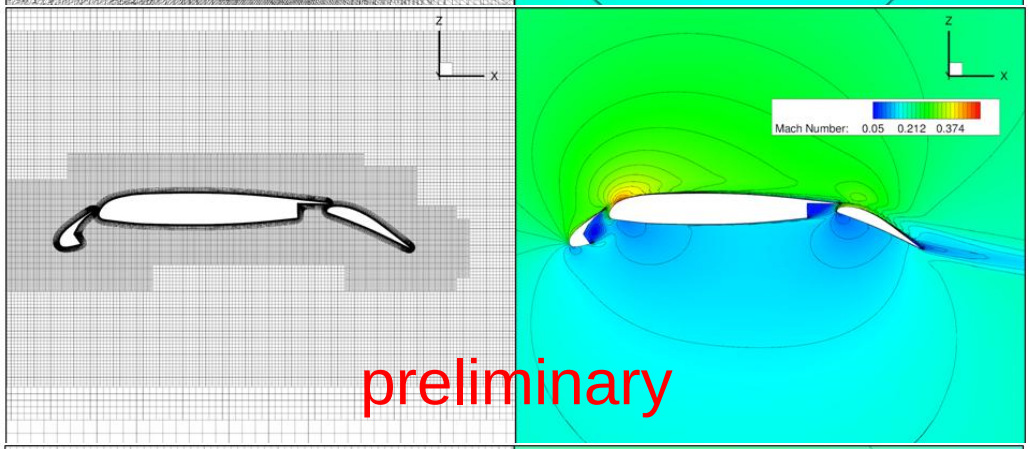
Additional Study – Off-Body Grid Refinement

Grid/Solution Comparison at $\eta = 0.50$, $\alpha = 13^o$



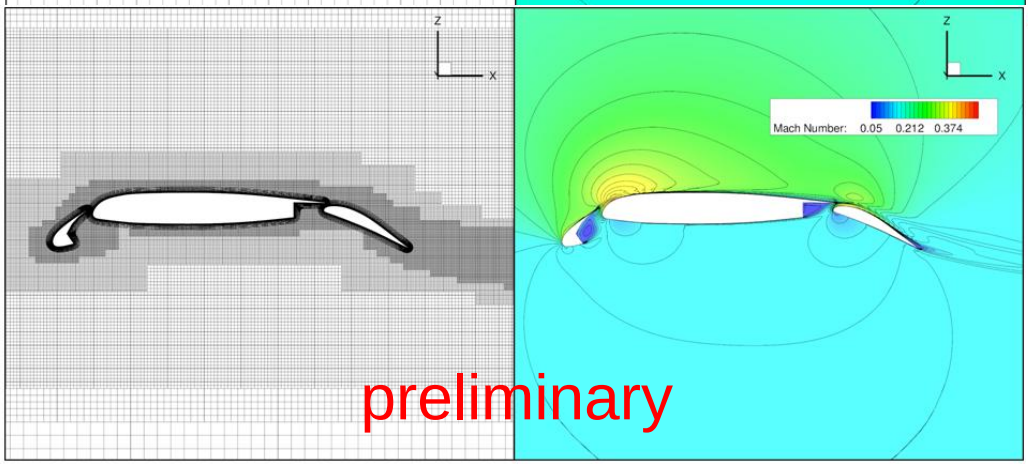
Medium Workshop Grid

- surface abutting = 17.6M points
- off-body = 7.4M points
- total = 25.0M



Cut-Down C-Mesh w/ Off-Body Cartesian Grids

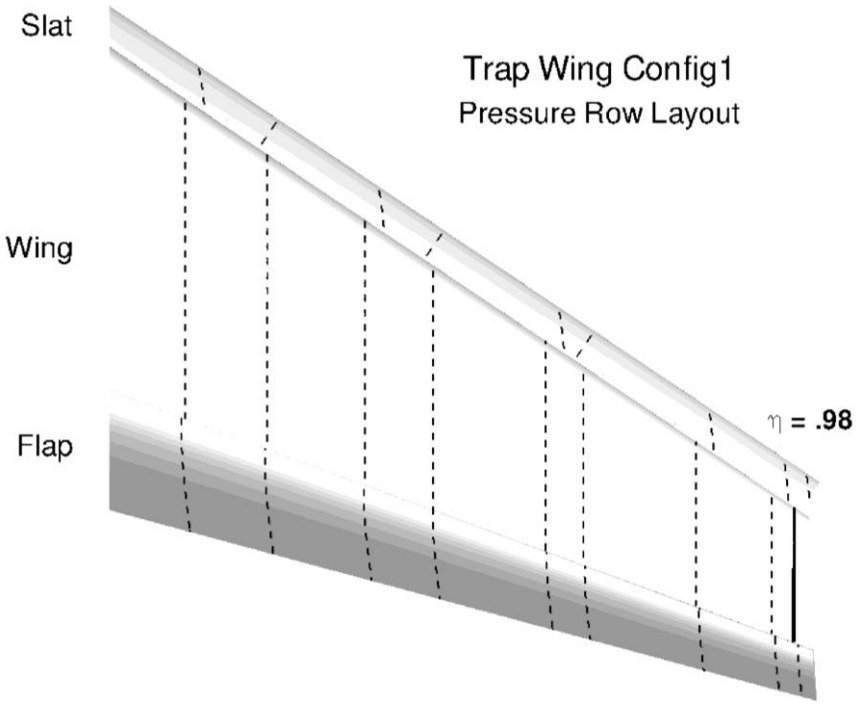
- surface abutting = 8.4M points
- off-body = 27.6M points
- total = 36.0M



Cut-Down C-Mesh w/ Level 1 Adapted Off-Body Cartesian Grids

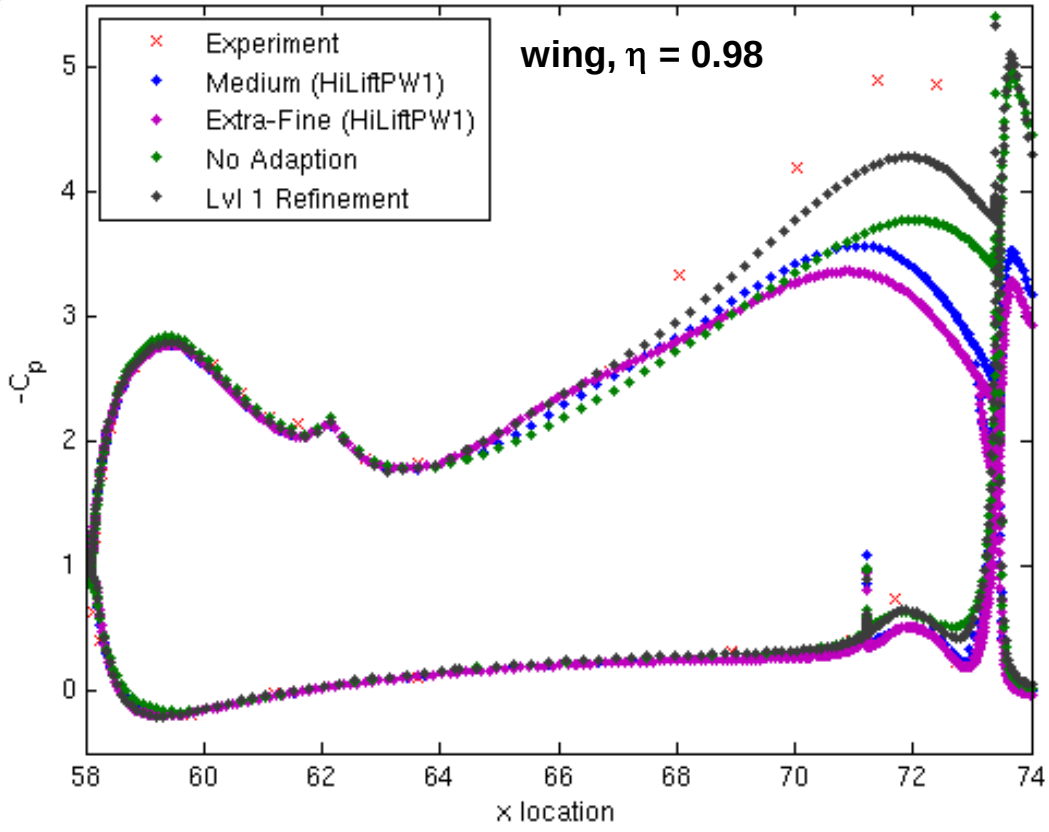
- surface abutting = 8.4M points
- off-body = 161.6M points
- total = 170.0M

Additional Study – Off-Body Grid Refinement
Pressure Comparison at the Tip, η = 0.98



OVERFLOW Trap Wing Config 1 Results

- fully turbulent, brackets off
- RN = 4.3 million
- Mach = 0.2
- $\alpha = 13^{o}$



Preliminary Grid Adaption Results

- Improved pressure comparison at tip with Level 1 refinement
- Adaption clearly puts the points where they need to be
  - Level 1 adaption is a better match to test data compared with the Extra-Fine grid results

Solution Convergence

- The solution strategy used in the Boeing Study was based on consistency (i.e., all cases run with the same Δt, I.C., and assumed steady state). This strategy does not guarantee the same level of convergence when grid spacing is greatly reduced and/or the flow field is characterized by unsteadiness.
- The solution strategy used in the NASA Study proved more effective at reaching consistent convergence levels. This strategy varied Δt and I.C. when needed and switched to time accurate calculations when all else failed.

Test Case 1 – Grid Convergence Study

- With the SA turbulence model, the coarse/medium/fine/extra-fine grid C_L results are close to linear when plotted against $1/N^{-2/3}$ and agree reasonably well with test data.
- Flap separation is over-predicted with the SST model particularly for the finer grids.
- In general, pressures are in good agreement with test data.
  - wing and flap pressures at the tip are the exception
  - flap suction peak and trailing-edge pressures predicted best using the SA-RC model

Test Case 2 – Flap Deflection Prediction Study

- Config 1 lift, drag, and pitching moment agree well with test data through stall.
- More discrepancy seen in the Config 8 force and moment data comparison at high α. This causes the incremental comparison to be off.

Test Case 3 – Slat and Flap Support Effects Study

- OVERFLOW results are in-line with expectations: brackets reduce lift.
- Should the bracket-off lift levels be higher than test data? It depends.
- Addition of brackets should reduce lift and addition of transition should increase lift. Current bracket-off, fully turbulent solutions just happen to agree.
  - no brackets, ⬆ C_L
  - fully turbulent, ⬇ C_L

These effects are opposite in sign.
More work is needed to see if they are equal in magnitude.

Additional Study – Off-Body Grid Refinement

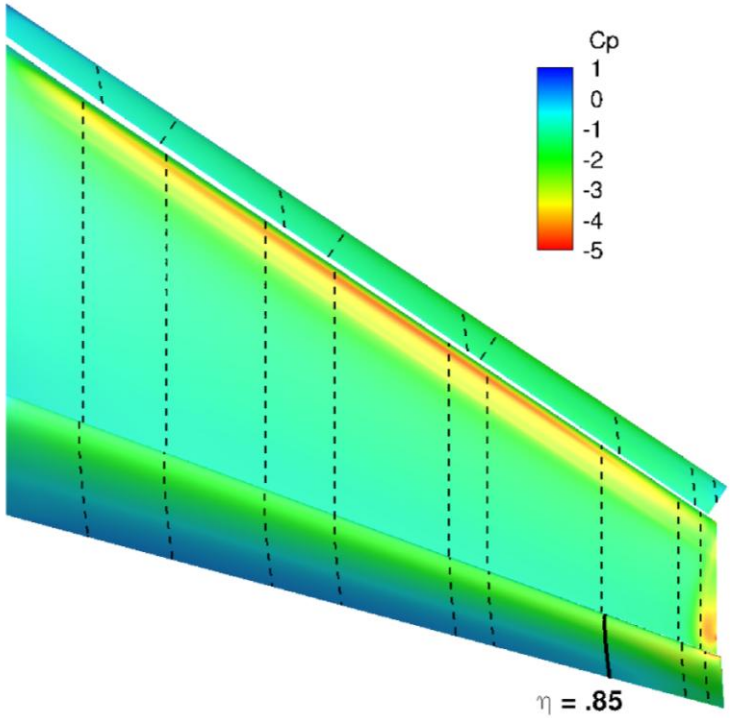
- Preliminary results from an off-body grid refinement study indicate the flow field at the tip can be adequately resolved with proper grid placement and density.

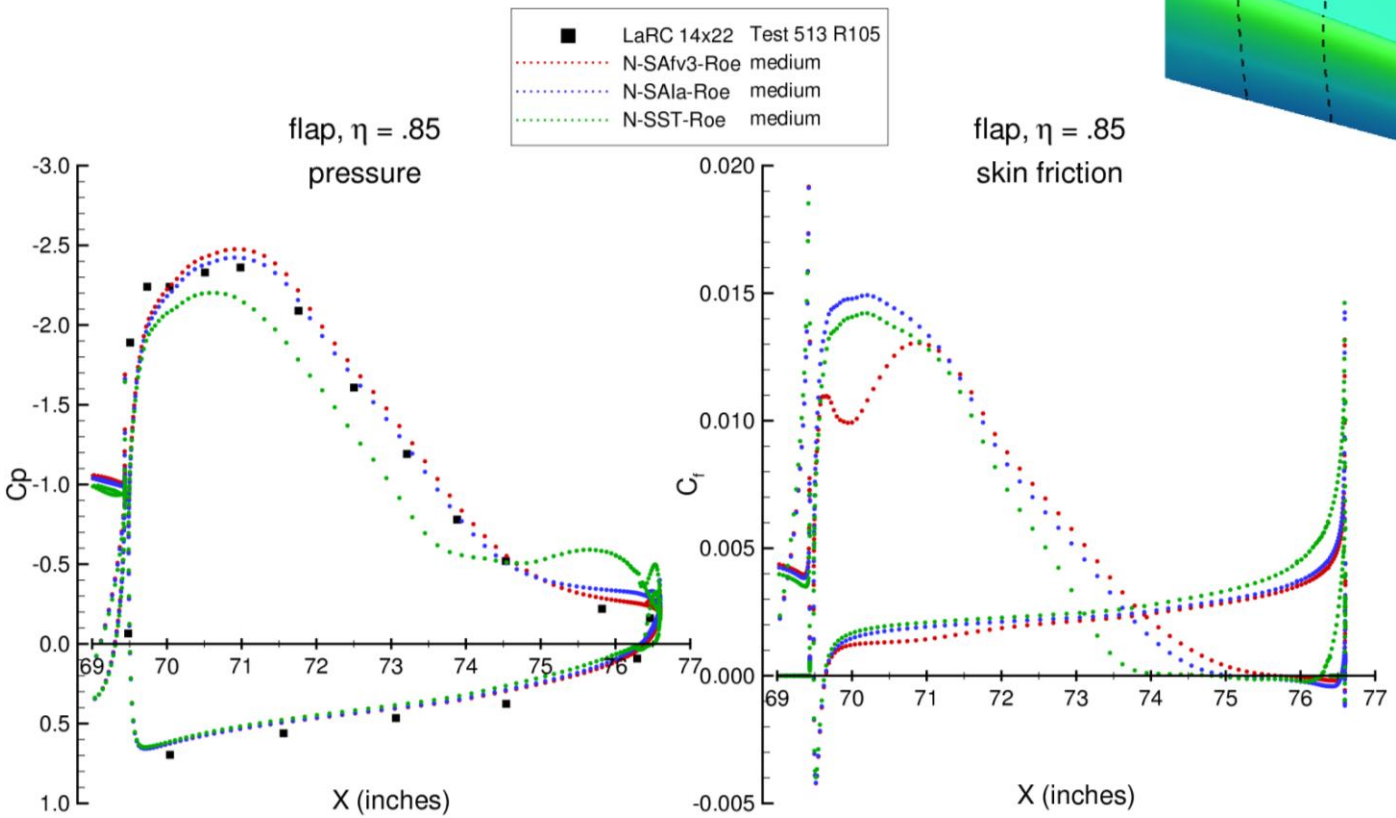
Questions?

Turbulence Model Effect: Flap η = 0.85
SA-Ia vs SA-fv3 vs SST

OVERFLOW Trap Wing Config 1 Results

- fully turbulent, brackets off
- RN = 4.3 million
- Mach = 0.2
- α = 13°

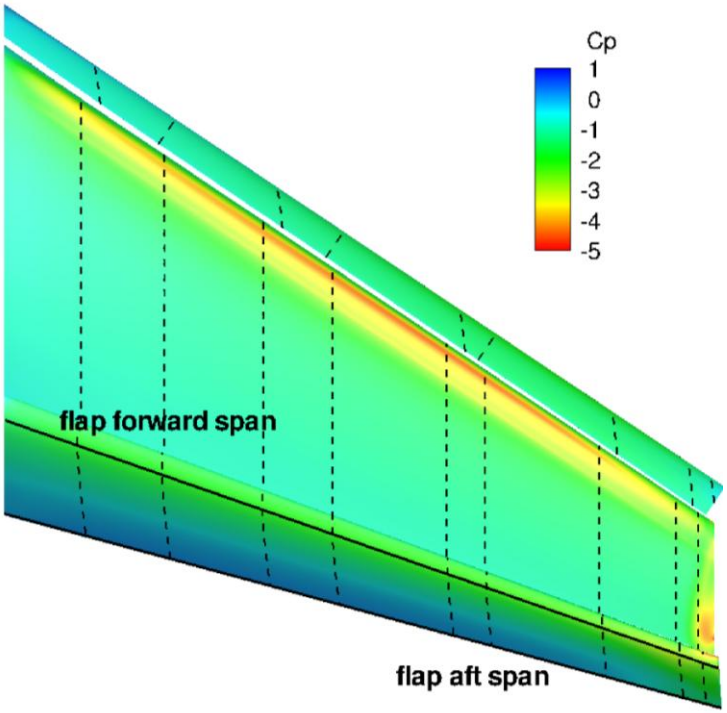


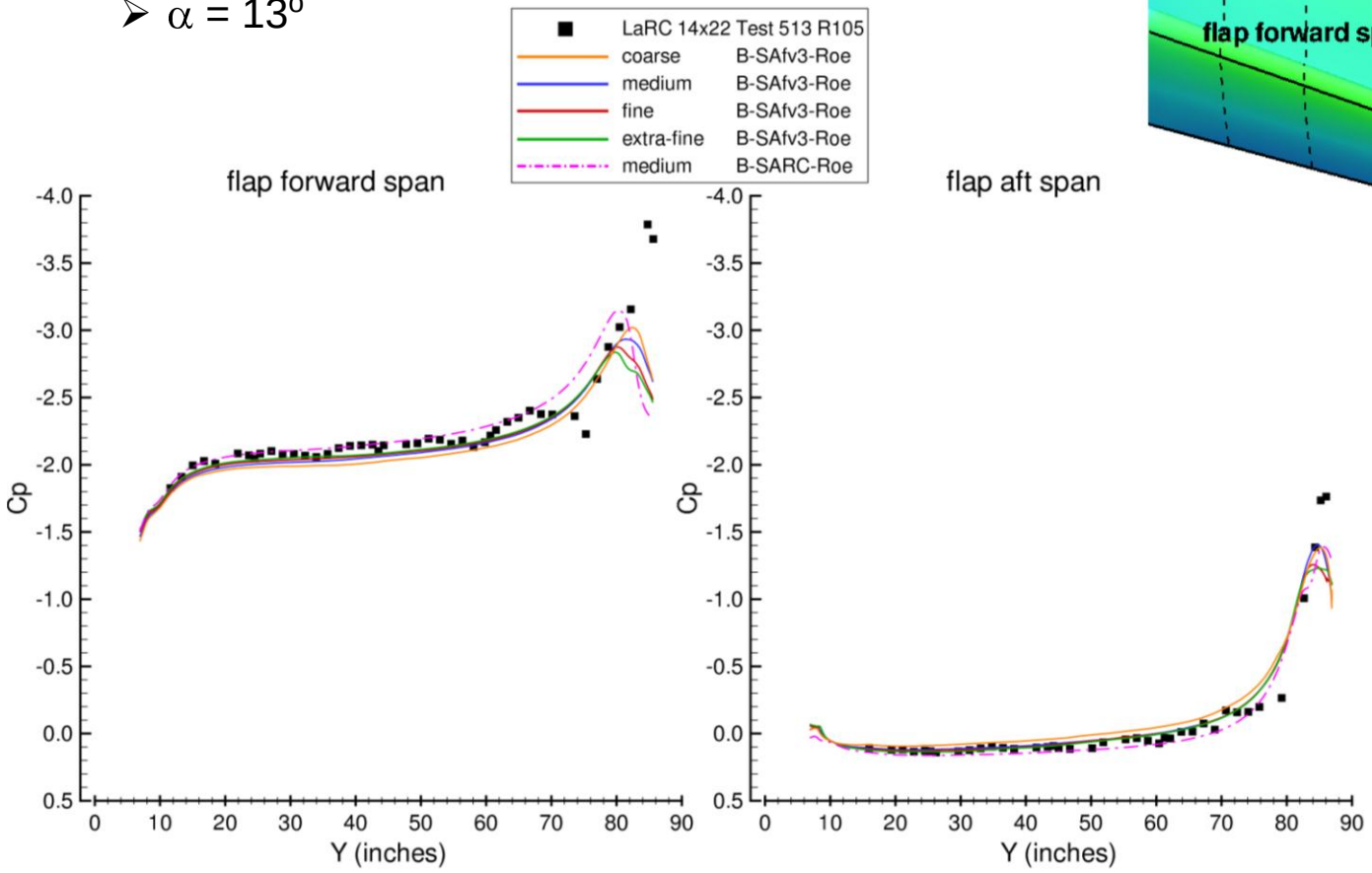


Turbulence Model Effect: Flap Span
SA-RC vs SA-fv3

OVERFLOW Trap Wing Config 1 Results

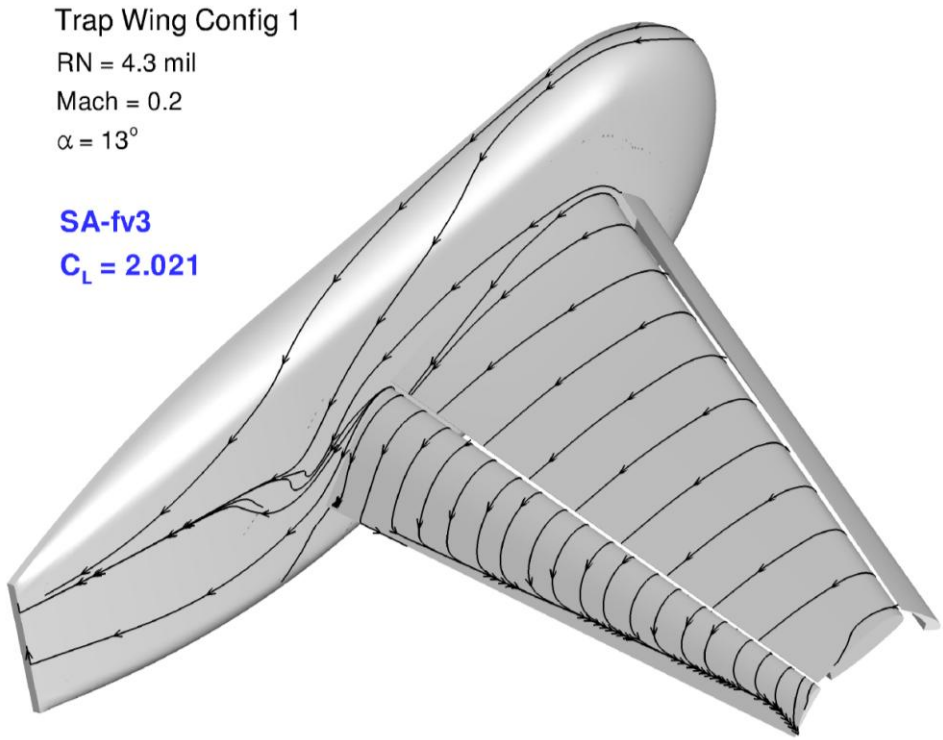
- fully turbulent, brackets off
- RN = 4.3 million
- Mach = 0.2
- $\alpha = 13^{o}$

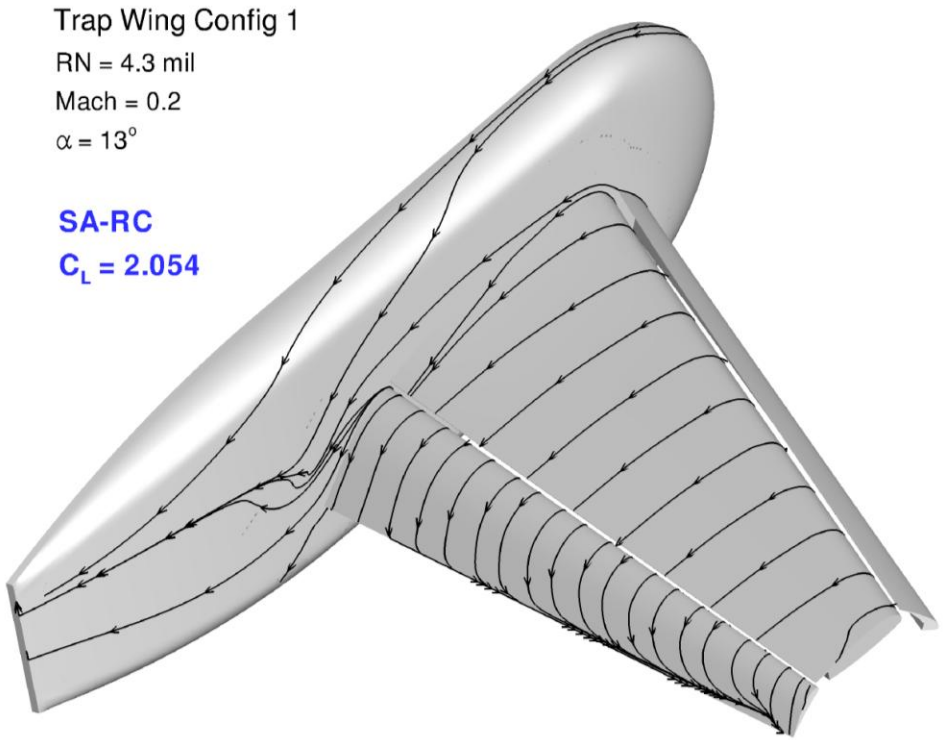




Turbulence Model Effect
SA-fv3 vs SA-Ia

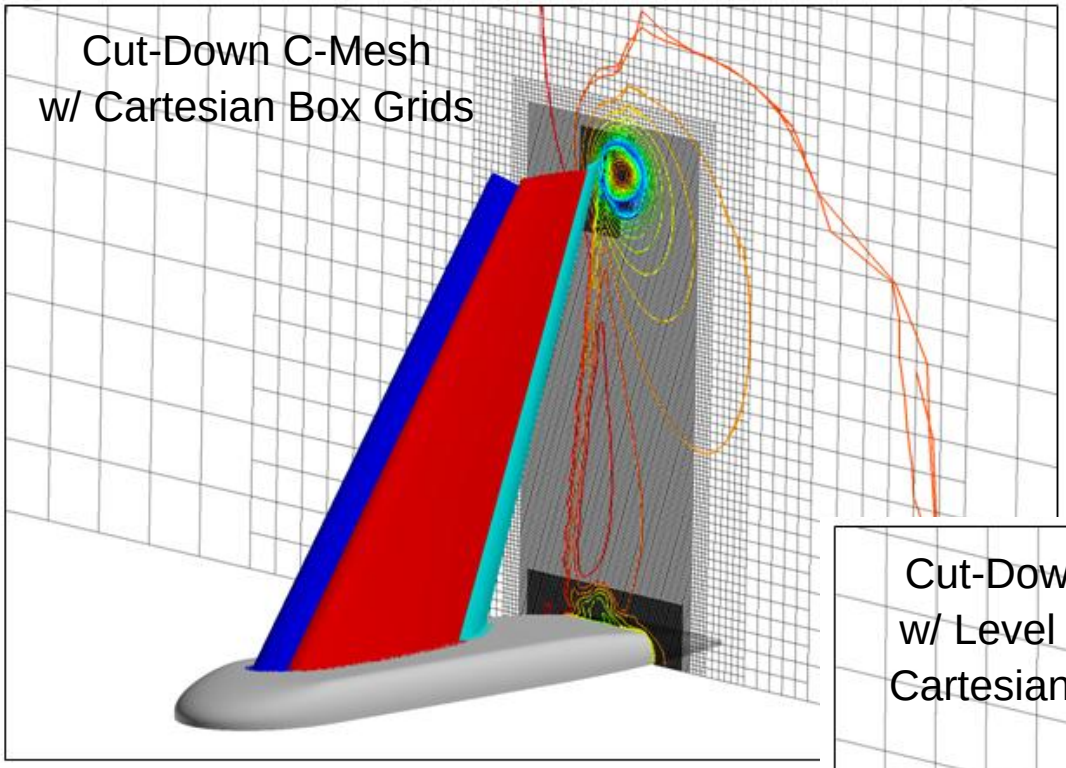
Considerably less flap TE separation predicted with the SA-RC model.





Additional Study – Off-Body Grid Refinement

Config 1 Tip Flow Resolution



OVERFLOW Trap Wing Results

- fully turbulent, brackets off
- RN = 4.3 million
- Mach = 0.2
- $\alpha = 13^{o}$